Canadian Airborne Hyperspectral Imager Development

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ABSTRACT

The Defence Research and Development Canada (DRDC) has embarked on a Technical Demonstration Program (TDP) to develop an airborne Hyperspectral Imaging System (HSI). This instrument is mounted in a Convair 580 turbo propeller driven aircraft and covers the 1.6 to 12 micron region of the electromagnetic spectrum. The spatial sampling of this system is determined by an 8x8 element detector array. Two arrays are operated simultaneously to cover the entire spectral region (InSb technology to cover 1.6 to 5.3 um region and HgCdTe technology to cover 2.5 to 12 um region). The spectral sampling is generated using a Fourier Transform spectrometer with a spectral resolution ranging from 1 to 16 cm-1. The frame rate of the system is variable (minimum of 16 Hz at 4 cm-1 spectral resolution). The instantaneous field-of-view (IFOV) of the instrument can be changed from 1.1 to 3.3 mrad, by interchanging collection telescopes (9x or 3x). The total field-of-view (TFOV) of this HSI is therefore small (8xIFOV) but may be pointed over a "field-of-regard" (FOR) 8 time that of the TFOV. In addition, Wide-FOV broadband cameras, operating in the visible, mid-wave and long-wave infrared bands, are used to register the entire FOR. An GPS/INS system is used to guide the pointing of the imaging spectrometer module. This instrument is essentially nadir looking and is based on the Ground-to-Air spectral imaging system (PIRATE) developed at DRDC Valcartier. The PIRATE system has been used to measure the 2-5 micron region with similar spatial and spectral resolutions as the airborne system. This project has completed the three-year system design and construction phase and is in the process of field-testing (up to four distinct scenarios) to evaluate its performance and begin assessing the "Military Utility of Airborne Hyperspectral Imagery". This paper will describe the instrumentation and present selected preliminary results.

1. INTRODUCTION

DRDC-Valcartier has developed an Air-borne Spectral Imaging System (AIRIS) based on the operational concept of their ground-based spectral imager "Pirate", that is, a "snap shot" based spectral Imager (8x8 pixel spatial resolution). This instrument is designed to operate as a "Target Interrogator" rather than a "Target Detector"; it is not a wide-area surveillance system. AIRIS is designed to be Nadir Viewing and operate primarily from a Convair 580 turbo propeller driven aircraft (see Figure 1). Although this is the platform of choice, the instrumentation is not restricted to only this airframe; it does however, require a 15-inch diameter Nadir-viewing hole in the aircraft.

The AIRIS system is based on similar modules used in the Pirate system. It uses a Fourier Transform Modulator to generate spectral resolutions (variable from 1 to 16 cm-1). It can be coupled to either a 3x telescope (3.6 mrad IFOV, 28.8 x 28.8 TFOV) or a 9x telescope (1.2 mrad IFOV, 9.6x9.6 mrad TFOV).

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The instrument can collect data at 16.7 Hz, at 4 cm-1 (about 30 Hz at 8 cm-1 and about 50 Hz at 16 cm-1).

The AIRIS system can measure emissions in the band 2.0 to 12 microns (830 to 5000 cm-1). This is achieved by acquiring data with two 8x8 element detector arrays simultaneously, one operating from 3.3 to 12 microns and the other from 2.0 to 5.3 microns. Data is collected directly to hard disk enabling collection times of up to 2 hours continuously (240 Gigabytes of raw H.S.I. data). In addition to the imaging spectrometer component of the AIRIS system is the broadband imaging unit. This unit contains three broadband imagers; a visible camera, a 3-5 micron mid-IR imager and an 8-12 long-wave IR imager. These cameras will be discussed in the following section.

Figure 1 - NRC Convair 580 Aircraft used by Airis.

2. AIRIS TARGET TRACKING UNIT

Target acquisition is performed using an opto-mechanical device that can track a target by using GPS/INS live information. Precise angular displacements are produced by four voice-coil activators that drive a steering mirror device that can be pointed to a target within a definite field-of-regard region (FOR). This FOR is roughly eight times the angular dimension of the hyperspectral imaging (HSI) instrument field-of-view.

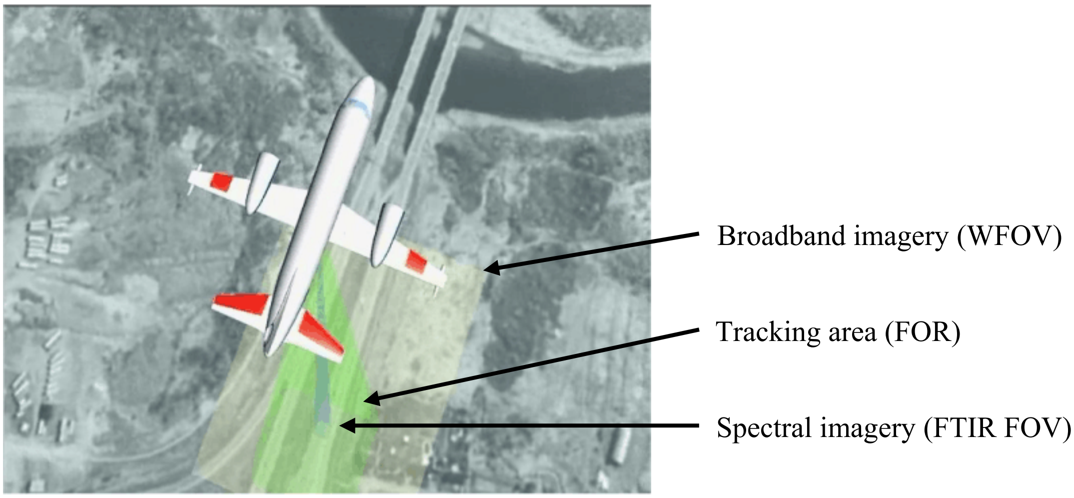


Figure 2 - Illustration of the three working areas: WFOV, FOR and FTIR FOV.

Three wide-field-of-view cameras are used to present a contextual image of the region-of-interest that includes the field-of-regard of the HSI instrument positioned roughly in the center. A portion of the wide-field-of-view, ahead in the flight direction, is used to visually assess an incoming target before it is kept locked within the HSI field-of-view by the opto-mechanical tracking unit (see Figure 2).

The three cameras cover the RGB visible, the Mid-wave infrared and the Long-wave infrared spectral bands. In this way, the operator can use the best image to assess a given target or to detect potential targets.

2.1 HSI optical configurations

The AIRIS instrument is designed to support two optical configurations named after their magnification power: the 3X and the 9X configurations. The 3X configuration utilizes a 3X afocal relay telescope and a flat mirror pointing/scanning system Presented in Figure 3 are the optical and CAD design elements.

The 9X configuration is obtained by replacing the flat mirror pointing/scanning system by a Gregorian type telescope adding a power of 3X to the previous telescope. The Gregorian telescope is designed with an oversized primary mirror and a movable secondary mirror allowing this system to point and track targets (see Figure 4). The optical design elements and the CAD design are presented in Figure 4.

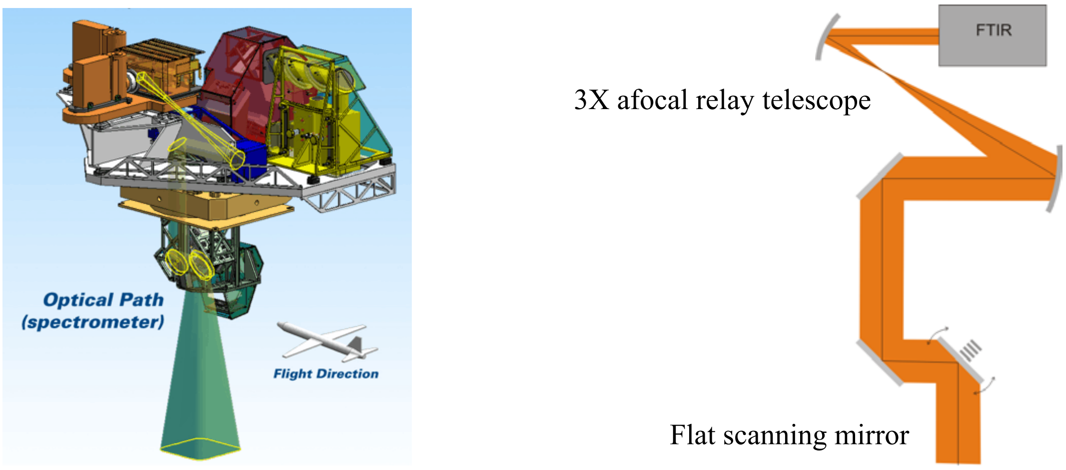


Figure 3 - 3X configuration. Right, ray trace view of FTIR optics. Left, CAD design view.

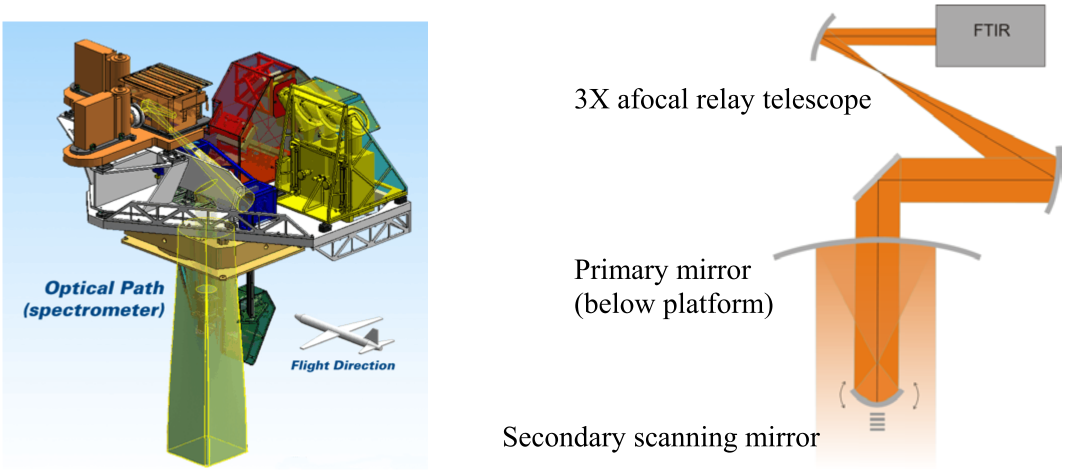


Figure 4 - 9X configuration. Right, ray trace view of FTIR optics. Left, CAD design view.

2.2 Navigation and tracking

The opto-mechanical pointing device is controlled by navigation software that uses the AIRIS GPS/INS unit to calculate the steering angle transmitted to the mirror. The GPS/INS unit uses its own antenna placed on the aircraft. The Inertial Measurement Unit (IMU) is attached to the AIRIS platform giving the exact attitude angle of the platform.

The software accepts a target list containing the latitude, longitude and altitude coordinates of existing targets. Using the aircraft coordinates, it is then possible to calculate the position of the target and indicate it into the WFOV image. In a similar manner, the steering mirror angular position and speed are updated in order to track the target. Table 1 lists the principal characteristics of the AIRIS software.

Table 1 - AIRIS Navigation Software Features

Monitoring of target acquisition and tracking	Identify targets in WFOV with symbol overlay, update target position as it moves in FOR on WFOV image
Target list management	Check list status to track only desired targets
Manual target position	Point & click on WFOV image to add manual targets on list
Target time remaining	Calculate time left to acquire a target (up to 5 minutes ahead)
Real time aircraft position/attitude	Latitude, longitude, altitude, azimuth, pitch and roll from GPS/INS
Real time steering mirror position	HSI FOV position overlaid on WFOV image, updated at frame rate
Manual altitude override	Force manual aircraft altitude
Target tracking filtering	Alpha-Beta filtering applied to attitude angles in order to smooth target tracking
Record complete event log	Real-time, full frame video recording of the three WFOV cameras. Steering mirror angles, targets event and aircraft position/attitude logs.
Replay event log	Replay a flight event including WFOV cameras video, steering mirror movements and targets event.

2.3 Instrument characteristics

The HSI instrument resolution is 10.7 mrad/pixel. The 3X relay will reduce it to 3.6 mrad/pixel and the Gregorian telescope will finally reduce it to 1.2 mrad/pixel. The resulting footprint of the instrument is presented in Table 2.

Table 2- AIRIS Footprint area

Altitude	1 km	2 km	3 km
9 x			
HSI pixel	1.2 x 1.2 m2	2.4 x 2.4 m2	3.6 x 3.6 m2
HSI FOV (8x8 pixels)	9.5 x 9.5 m2	19.0 x 19.0 m2	28.6 x 28.6 m2
Tracking zone (64x64 pixels)	76 x 76 m2	152 x 152 m2	228 x 228 m2
3 X			
HSI pixel	3.6 x 3.6 m2	7.1 x 7.1 m2	10.7 x 10.7 m2
HSI FOV (8x8 pixels)	29 x 29 m2	57 x 57 m2	86 x 86 m2
Tracking zone (64x64 pixels)	228 x 228 m2	457 x 457 m2	685 x 685 m2

The amount of time left to acquire the target depends on aircraft speed and altitude. The average aircraft speed being approximately 100 m/sec, the time left can be, in certain situation, less than a second (Table 3). Considering the fact that a low altitude flight is prone to higher turbulence, this can be very demanding on the tracking system.

Table 3- FTIR acquisition time

Altitude	1 km	2 km	3 km
9 x			
Time in tracking zone	.76 sec	1.5 sec	2.3 sec
3 X			
Time in tracking zone	2.3 sec	4.6 sec	6.9 sec

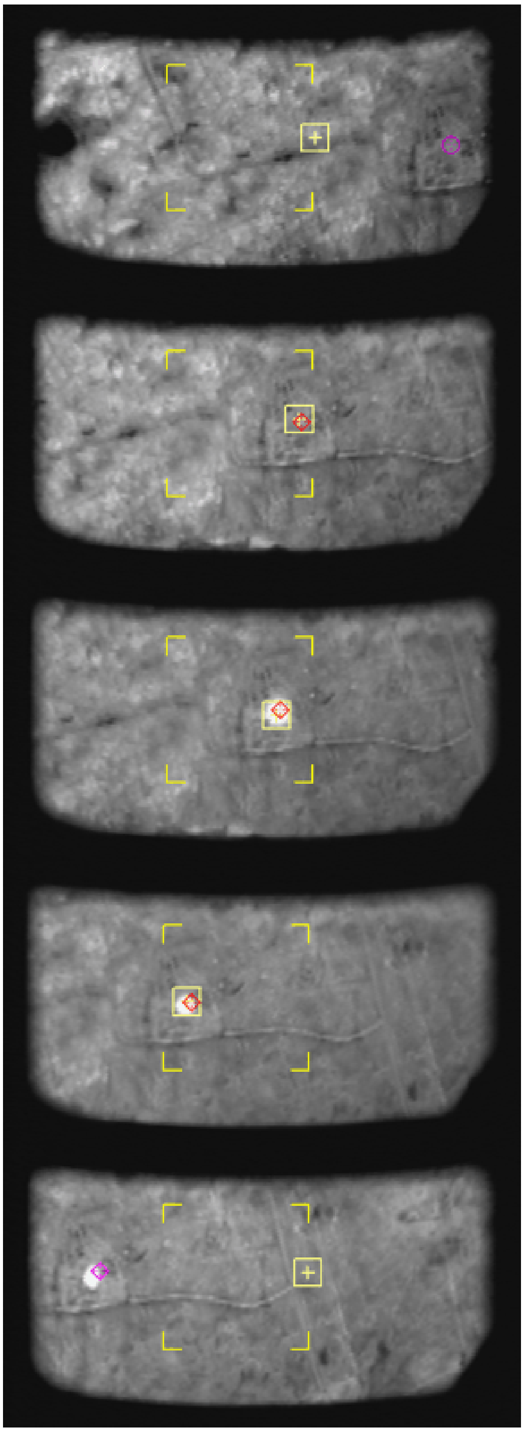
2.4 Flight sequence example

Figure 5 presents a series of images taken with the LWIR camera during a flight over an explosion event. During this flight, the explosion countdown was taken from the AIRIS software and given by the pilot to the site officer.

The sequence illustrates the different steps of the target acquisition process. Of these steps, two are not illustrated: First, the time remaining to the target to arrive at the frontier of the FOR is presented in the target list window. Second, the target indicator will appear in a grey zone representing the ground space in front of the aircraft that is not viewed by the cameras. This gives a relative target position before it actually appears in the camera image.

From there, the target indicator will be overlaid on the target during the aircraft passage over it. Its position on the image results from a calculation using the aircraft and the target coordinates.

When the target enters into the FOR, it is locked into the HSI FOV by the tracking unit as long as it is in the FOR. The mirror steering angle is also calculated from aircraft and target coordinates. The operator can follow the process with the HSI FOV imaged by a yellow square and placed in the camera image according to its actual position in a fame-by-frame basis.



Target position is calculated and shown in WFOV image (blue indicator) in the incoming target region.
The HSI FOV (yellow square) is placed in position at FOR border.

The target indicator turns red, indicating that the target is tracked by the scanning mirror.

The explosion event is captured and measured.

The explosion event is tracked and measured as long as it is inside the FOR.

The target indicator turns blue, and continues to mark the target as it moves out of the camera FOV.
The mirror comes back to its waiting position.

Figure 5 - Ground explosion flight sequence showing the target acquisition and tracking process as viewed in WFOV.

3. HYPER SPECTRAL MEASUREMENT EXAMPLES

Figure 6 illustrates the 2.0 to 5.3 micron hyperspectral measurement of the aforementioned explosion (20 kg of explosive). This measurement is one of a series taken at a rate of 50 Hz (16 cm-1 spectral resolution with the aircraft at an altitude of 3 km). For this example the 3x telescope configuration was used with the

entrance aperture reduced from 3 inches to a 1-inch diameter. In addition, the detector was attenuated with a 3% transmission neutral density filter. Each pixel corresponds to an area on the ground of 10.8x10.8 meters.

The total spectral signature versus time-into-burn representation is shown in Figure 7. Although the aircraft was travelling at 100 meters/second, target track time was sufficient to allow for a complete temporal description of this event.

An example of a multi-target track is given in Figure 8 in which the peak pixel intensity in each measurement frame is plotted as a function of time along track. In this example 6 separate target tracks can be easily identified. These measurements were made using the 3x telescope configuration at an altitude of 1 km, resulting in pixel coverage on the ground of 3.6 meters squared. All targets were sub-pixel.

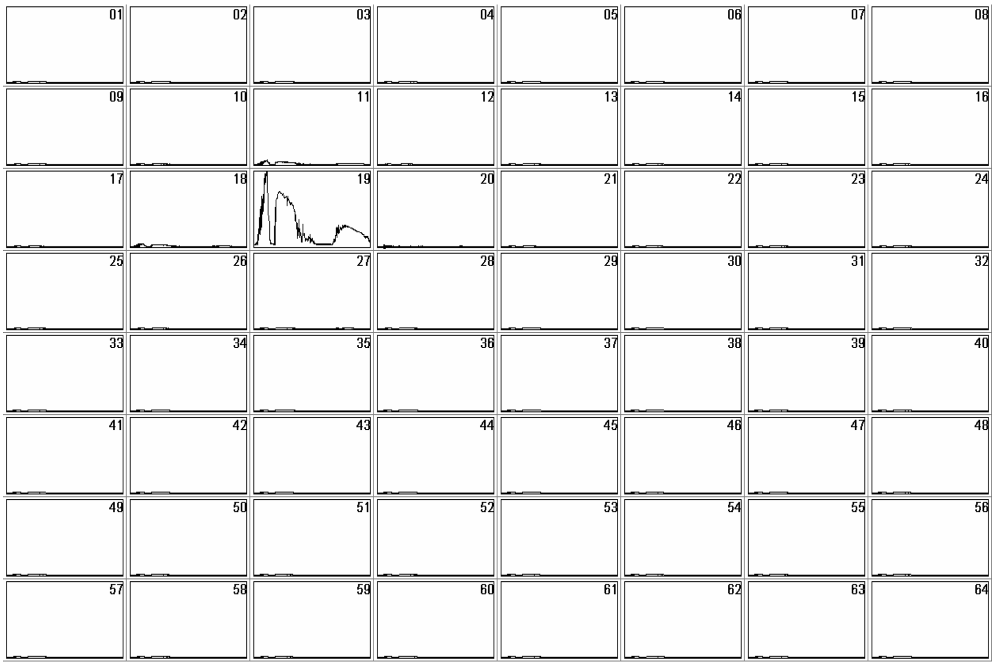


Figure 6 - Frame Representation of a single explosive measurement (2.0 – 5.3 um) (3 km altitude using 3x telescope).

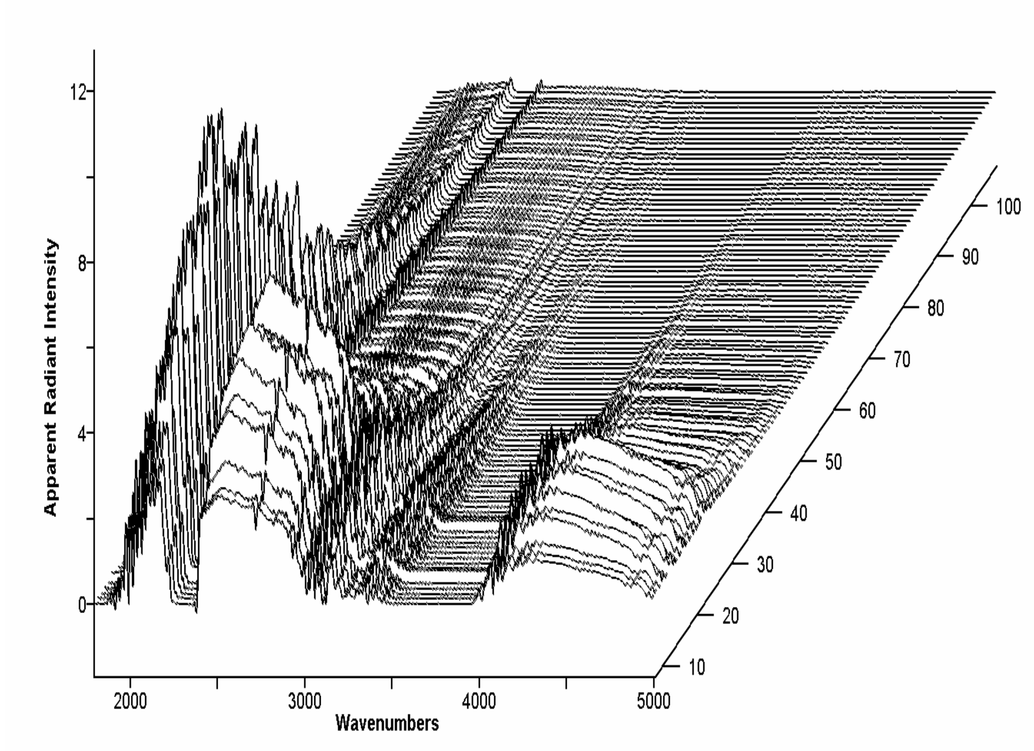


Figure 7 - Total Signature versus Scan Index (50 Hz) for event shown in Figure 6

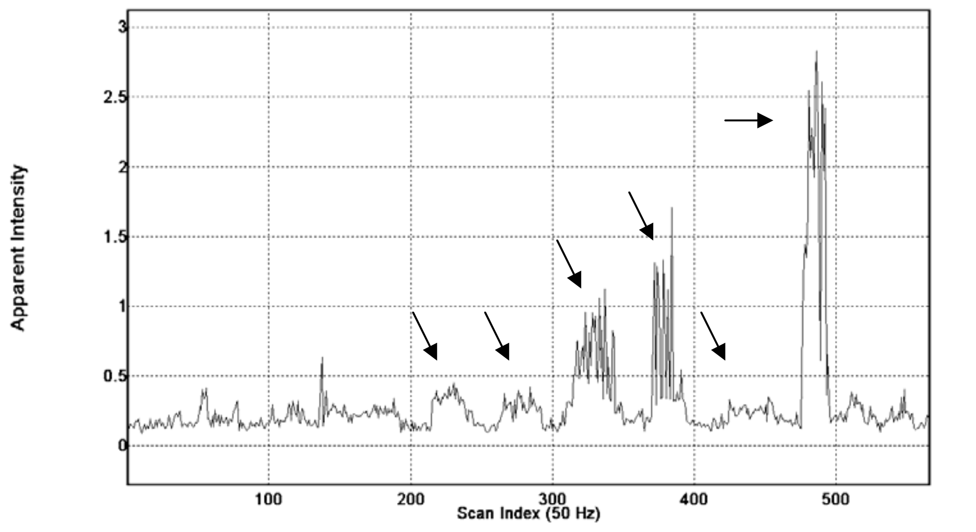


Figure 8 – Total intensity versus Scan Index illustrating 6 targets tracked (between scans 200 and 500).

4. CONCLUSIONS

Thus far the AIRIS instrumentation has been flown on the NRC Convair 580 aircraft and used to collect target data on land and sea at altitudes ranging from 21,000 ft to 300 feet. The spectral imager has been used at spectral resolutions ranging from 1 to 16 cm-1 at single scan rates of 4 to 50 Hz (respectively). In addition, spectral co addition has also been performed. Both single and dual detector operation has been successfully exercised. Telescope exchange is typically performed in less than one hour; though not while in-flight. Target emission intensities measured have varied from those emanating from explosives, on one extreme, to targets at ambient temperatures on the other. Low altitude turbulence has been found to move targets from pixel to pixel while tracking. This behaviour is most severe over land at low altitudes (3000[1] feet or less). From the beginning of July to the end of August, AIRIS has been used to collect over one terabyte of raw hyperspectral imagery. Processing of this raw is currently ongoing.

[1] NOTE: DRDC web site www.drdc-rddc.gc.ca . Valcartier laboratory see www.valcartier.drdc-rddc.gc.ca